The Evolution of Software Development at HEC

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7 January 2010

US Army Corps of Engineers
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In the Beginning….

- Hydrologic Engineering Center (CEIWR-HEC) established in 1964.
- Mission was to develop techniques to promote hydrologic engineering and enhance its state-of-the-art. We did this by performing research and software development and by providing training and technical assistance in hydrologic engineering for Corps offices.
- To accomplish our mission, HEC created a family of high quality software that could be used efficiently by the field.
- Several single purpose programs were released in 1964 and HEC's first major software releases were in 1968.

In the Beginning….

- Software was written in FORTRAN, the Corps obtained its scientific and engineering computer processing offsite (Lawrence Berkley Laboratory (LBL)), the computers were mainframes, coding was done on punched cards, and output was provided on paper.

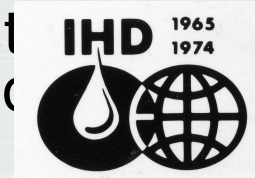
In the Beginning….

- All coding was contained in a card deck, which was picked up by a courier once a day, delivered to LBL and then the next day you would receive output.

- Each time a software package was computed, the entire card deck had to be read through a card reader.

International Hydrological Decade
(1964 – 1974)

- The International Hydrological Decade (IHD) program was a worldwide effort under the leadership of the United Nations Educational Scientific and Cultural Organization (UNESCO) to focus on hydrological studies, advancing the knowledge on the science of water and to improve techniques needed to meet the rapidly increasing demand on water.
- The Corps' contribution to IHD (Generalized Hydrologic Design Criteria) began in 1966 and ended in 1974 and was under the purview of HEC.
- HEC was tasked by members of IHD to develop, test document and train engineers on these new metho



IHD

The training and documents focused on practical hydrologic engineering techniques using HEC software. The cooperative studies were initiated to test the techniques that were presented and implemented in HEC software and were the first HEC involvement in international projects.

HEC Software Development
'HEC Business Model'

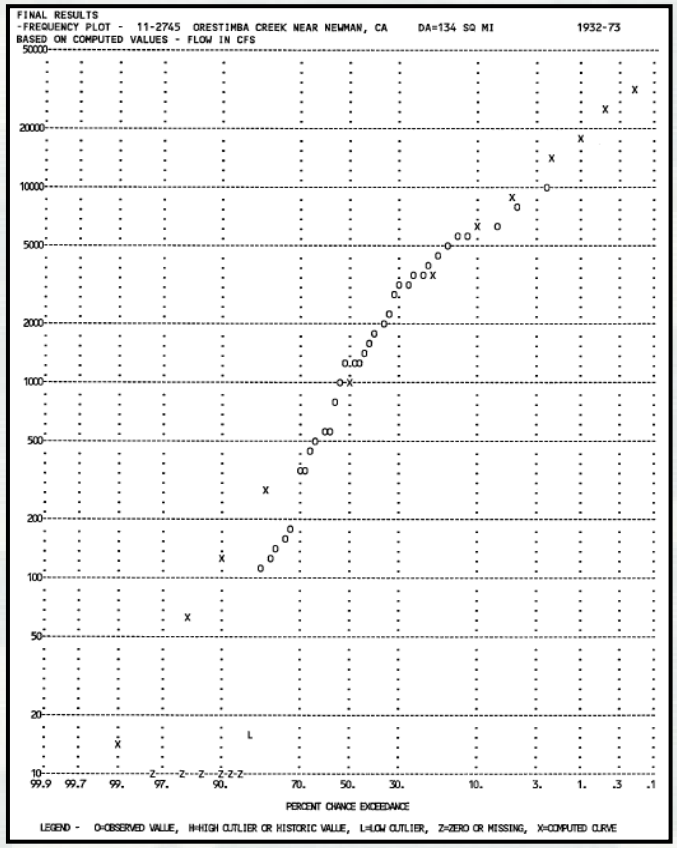
- HEC exists to help the Corps perform it's Civil Works mission in a world-class manner.
  - The work of the Corps is performed at the field office level.
  - HEC products and services are for field use and application.
  - HEC products are generic and can be used anywhere in the world.

First Decade
(1964 – 1974)

- Software development efforts were initially targeted at computerizing existing analysis methods that were documented in Corps guidance.
- Several single purpose programs with limited scope were released – unit hydrograph computations, basin rainfall, stream flow routing and others with similar functions.
- In the late 1960s these single purpose programs were integrated into more complete software packages such as HEC-1, HEC-2 and HEC-3.

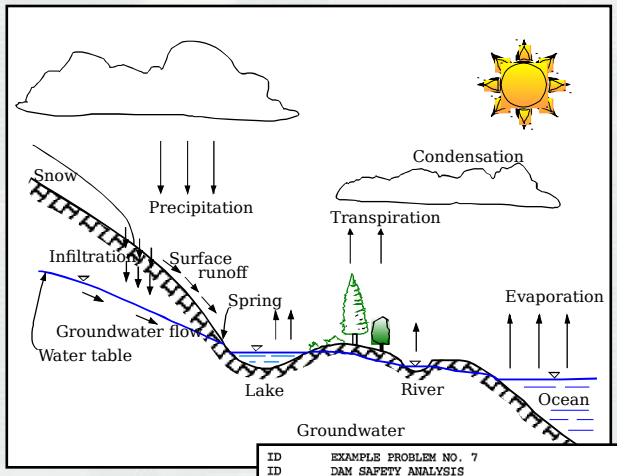
First Decade

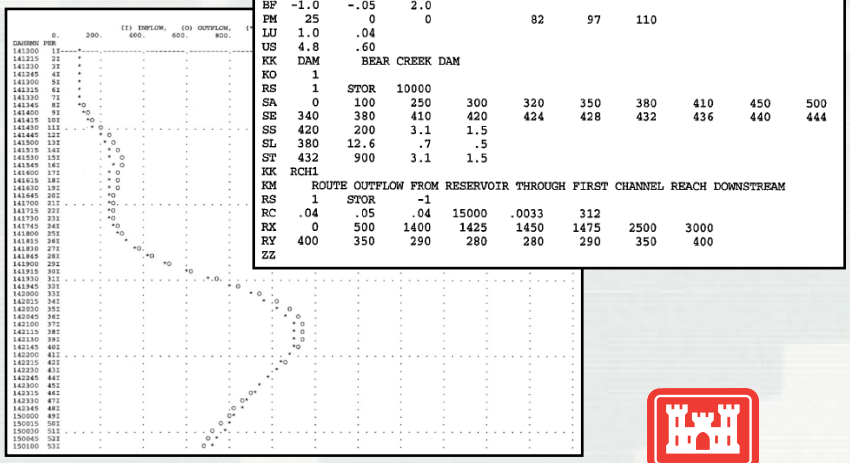
- Computer hardware during this period was mainframe computers, input was on punched cards and output was numerical/text with graphics represented as line printer plots.
- User documentation consisted of User's manuals, a few Programmer's manuals and presentations created for training courses. Support was provided to everyone through training courses, telephone support and systematic maintenance of the software.



HEC-1, Flood Hydrograph Package

- First version completed in the Fall of 1968; provided a comprehensive description of the hydrologic cycle, combining precipitation, infiltration, surface runoff, baseflow, channel routing and reservoir simulation.
- Now possible for engineers to focus on the hydrologic process instead of making manual calculations.
- By the end of the 80's, HEC-1 had been used extensively and had shown the value of using software for hydrologic simulation.

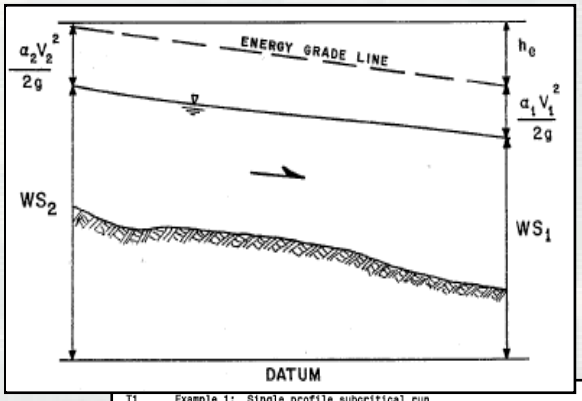




```
ID        EXAMPLE PROBLEM NO. 7
ID        DAM SAFETY ANALYSIS
ID             ANALYSIS OF DAM OVERTOPPING USING RATIOS OF PMF
IT    15        0        0      121
IO     5
JR  FLOW     .20      .35      .50      .65      .80     1.0
KKINFLOW    INFLOW TO BEAR CREEK RESERVOIR
BA  72.1
BF  -1.0     -.05     2.0
PM    25        0        0                82       97     110
LU   1.0      .04
US   4.8      .60
KK   DAM       BEAR CREEK DAM
KO     1
RS     1     STOR    10000
SA     0      100      250      300      320      350      380      410      450      500
SE   340      380      410      420      424      428      432      436      440      444
SS   420      200      3.1      1.5
SL   380     12.6       .7       .5
ST   432      900      3.1      1.5
KK  RCH1
KM      ROUTE OUTFLOW FROM RESERVOIR THROUGH FIRST CHANNEL REACH DOWNSTREAM
RS     1     STOR       -1
RC   .04      .05      .04    15000    .0033      312
RX     0      500     1400     1425     1450     1475     2500     3000
RY   400      350      290      280      280      290      350      400
ZZ
```

HEC-2, Water Surface Profiles

- In the early 60's, hydraulic engineers developed water surface profiles by hand solving the Energy equation using the Standard Setup Backwater method.
- In 1964, the Backwater – Any Cross Section software was released, written in WIZ. In 1966 the software was re-written in FORTRAN and released.
- In 1968, the first official version of HEC-2 was released and established HEC's role in river hydraulics. Quickly became an international standard for computing water surface profiles.




```
T1     Example 1:  Single profile subcritical run
T2     Output options include: User design summary, flow distribution, suppress
T2       printer plot of profile, and cross-section printer plot.
T3     Bear Creek
T4     Input options include: Effective area option, encroachment method 1,
T5       add points, repeat cross section, and change discharge.
*   Starting with energy slope and estimated water surface elevation
J1                    0.0092                          7800 1756.02
*   Supress profile printer plot (J2.3 = -1)
J2                    -1
*   User designed output with variables and defined table (150)
J3    38      1       3      57      68     150

NC    .1      .1     .04      .1      .3

*   Use effective area option to only consider overbank when channel banks are
*   exceeded (X3.1 = 10).
*   Use left encroachment to block low overbank area beyond station 183 (X3.4&5)
X1    1.0      60     767     815       0       0       0
X3     10             183    1757
GR1767.0       0  1765.4      23  1763.5      49  1762.0      69  1759.1      87
GR1758.1     103  1756.9     113  1756.9     122  1753.2     127  1753.1     131
GR1757.7     140  1757.7     152  1755.0     160  1755.6     168  1755.6     171
GR1755.6     174  1754.7     177  1755.9     183  1756.0     190  1754.9     208
                                                                             352
                                                                             452
                                                                             613
                                                                             750
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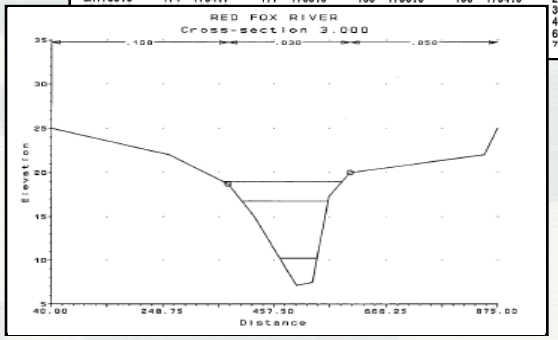
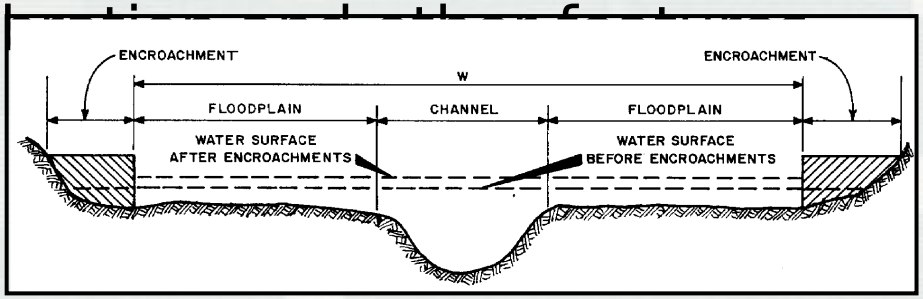


HEC-2

- Several versions of the software were made available during the 70's and 80's. Various new features were added – bridge hydraulics, culvert hydraulics, channel improvements, automated Manning's n value calibration and other features.
- By the end of the 1980's, HEC-2 along with becoming an internationally accepted



standard tool, also became an integral part of the Federal Emergency Management Agency's (FEMA) flood insurance studies program for the computation of water surface profiles.

Where did the Needs/Ideas Come From?

- Field Review Groups
- Training Classes
- Reimbursable Work
  - ► Corps offices
  - ► Partners
- HEC Engineers

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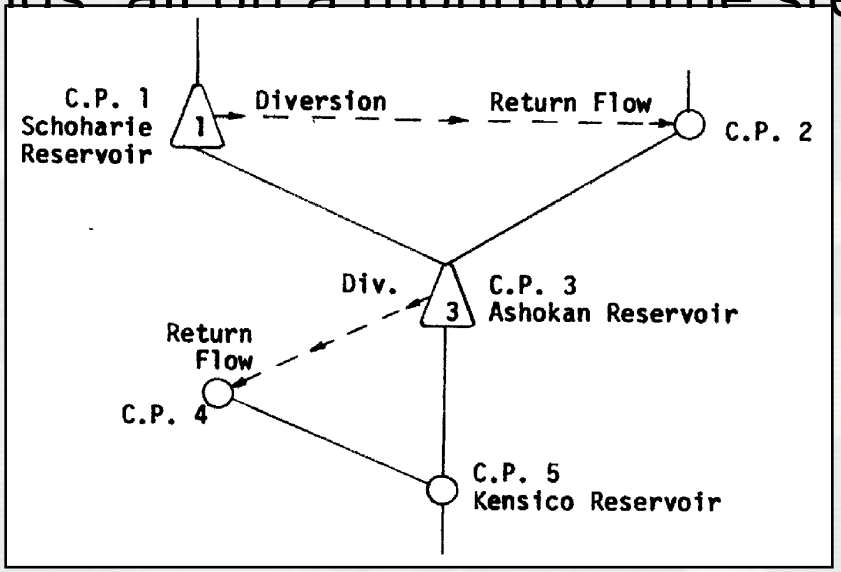
HEC-3, Reservoir System Analysis for Conservation

First version released in 1968, this generalized, multi-reservoir simulation software could simulate almost any configuration of reservoirs, diversions, and downstream control points for water supply, hydropower and diversion demands, all on a monthly time step.



HEC-4, Monthly Streamflow Simulation

- First version released in 1968, HEC-4 was a synthetic streamflow generation tool, estimating missing values for average monthly streamflow.
- The last revision to the software occurred in 1982. The software was converted to PC.

Second Decade
(1974 – 1984)

- HEC expanded their software development into the creation of a data management system, the beginning of the real-time water control software (WCDS), HEC-5, a package of flood damage analysis software, water quality, statistical analysis, early implementation of GIS and a family of graphics, utilities, and data communications software.

- By the end of this decade punched cards had disappeared, input was being done through remote terminals, output was generally sent to line printers, though graphics was becoming more important.

Second Decade

- Mainframe computers were still in use, minicomputers were being used later in the decade. Very late in the decade, HEC was introduced to the first personal computer (IBM AT).

- Use of HEC software greatly expanded, which lead to an impact on user support. Documentation was expanded and became more sophisticated, programmers manuals became obsolete and application guides were created. Support was still provided to all, but by the end of the decade HEC started restricting support.

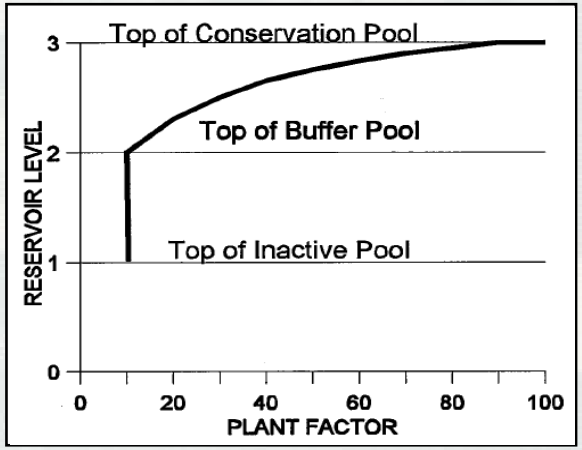
HEC-5, Simulation of Flood Control & Conservation Systems

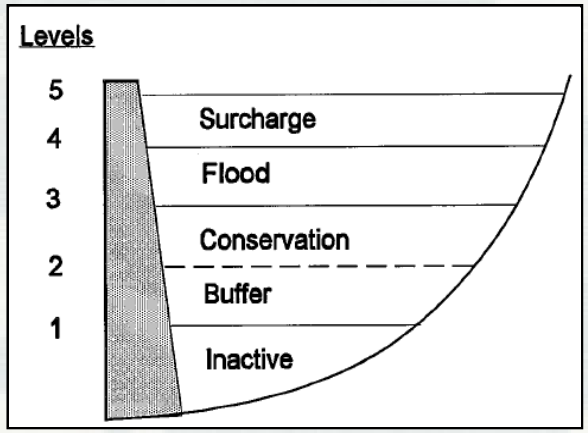
- First version released in 1974 and incorporated most of the functionally of HEC-3. Developed to meet the need to model flood control operations at an hourly or daily time step for a single event.

- Throughout the decade the software was enhanced to include all the conservation features of HEC-3 and include continuous simulation for period of record analyses.

HEC-5

- During the decade, requests from Corps office for additional features expanded capability to represent flood control, water supply, hydropower and real-time flood operation. Later in the decade, water quality was added (HEC-5Q, 1980) to the software.
- Several utility programs were created to facilitate the development and analysis of HEC-5 models.
- The last release of the HEC-5 software was in 1998.



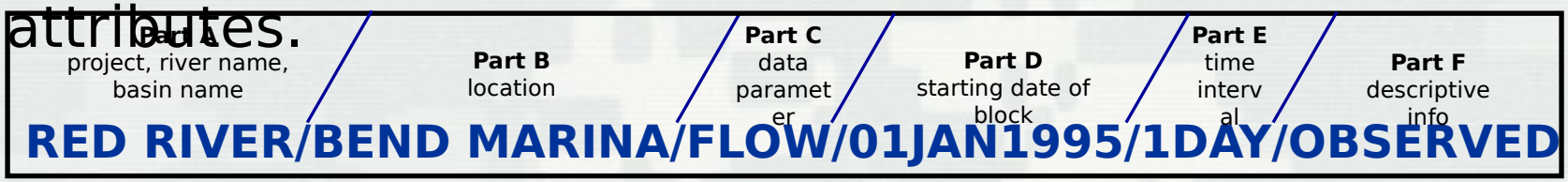


HEC-6, Scour & Deposition in Rivers & Reservoirs

- First official version was in 1976. Using mobile boundary modeling techniques was a first.
- Simulates one-dimensional sediment transport, scour and deposition in a river system that may have reservoirs. Accounts for armoring and simulates the movement of a range of grain sizes from clays to coarse gravels.
- Most of the HEC-6 functionality has now been incorporated into the HEC-RAS software.

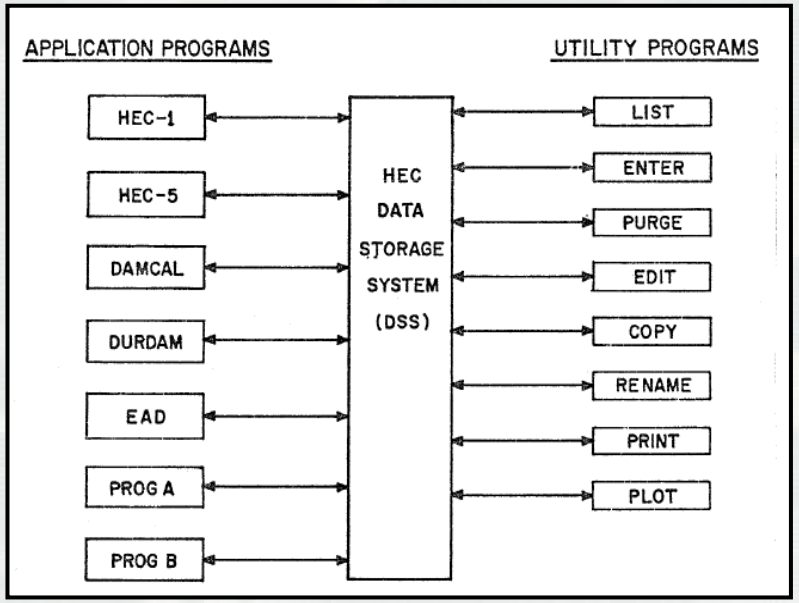
HEC-DSS, Data Storage System

- First version released in 1979 and was developed to manage data storage and retrieval needs for water resource studies.
- DSS is based on an index of pathnames that point to data records. The concept of a pathname provided a simple way of identifying the data being stored. In turn this allowed user choice of names with fixed identifiers of data type, which ensured consistent self-documentation of data, units, and other attributes.



HEC-DSS

- All the major HEC software packages implemented DSS functionality, so by the mid-1980's DSS was a critical component to efficient Corps hydrologic studies and water management activities.
- The features and capability of HEC-DSS now exist in the HEC-DSSVue software.



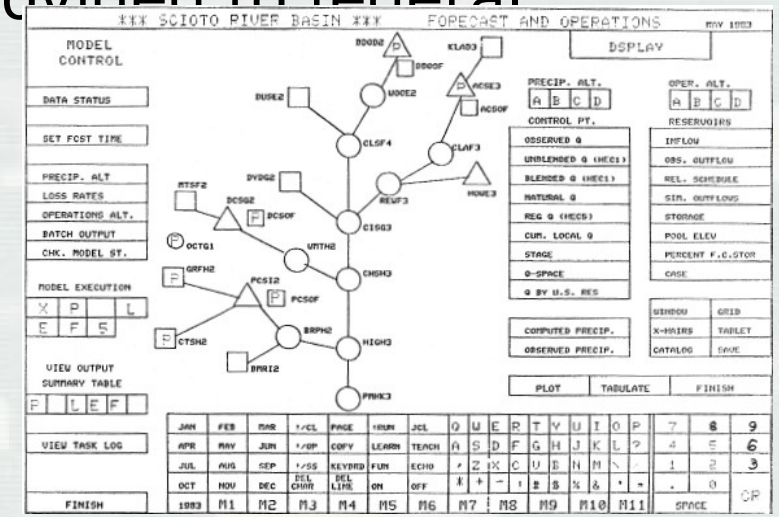
Third Decade
(1984 – 1994)

- With the introduction of PCs, HEC software and support of that software encountered big changes. In 1984 HEC released a PC version of HEC-2 and during the decade released PC versions of HEC-1, HEC-5, HEC-6, DSS, a package of flood damage analysis software and several other existing software packages were moved to the PC environment.

- HEC released a text editor (COED) to better meet data entry needs; built menu shells for our major software packages; developed software installation guides; and, set forth standards for PC file management.

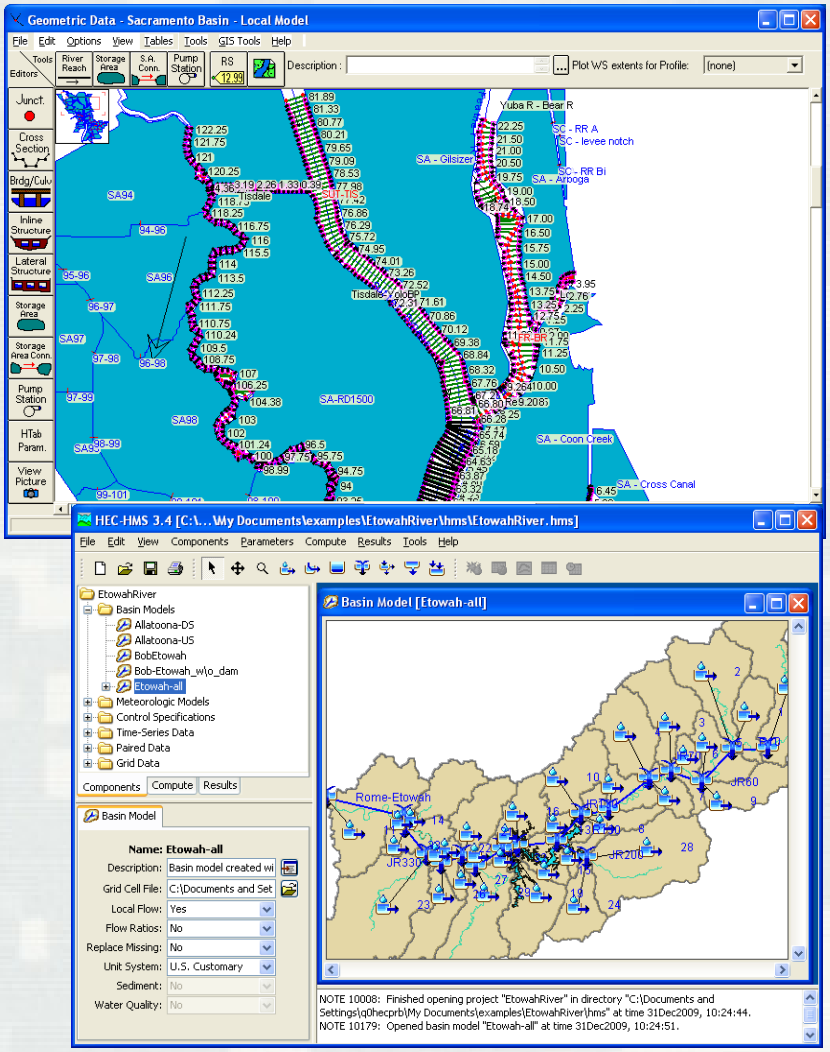
Third Decade

- Now that our software was more useable and widely available, support became unwieldy. With increases in distribution, training, and telephone support, HEC in 1988 established a position where support and distribution would only be provided to federal entities.
- Mainframe software development and support was reduced but not forgotten. The water control software (WCDS) being used within the Corps was significantly expanded during this decade.



NexGen

In 1990, HEC started a new R&D project to design and develop the next generation (NexGen) of HEC software. This project was targeted with developing successor generation software packages for the H&H engineering community of USACE. Five major areas were identified, technical and software support teams were formed: HEC-HMS, -RAS, -FDA, ResSim and -DSSVue.

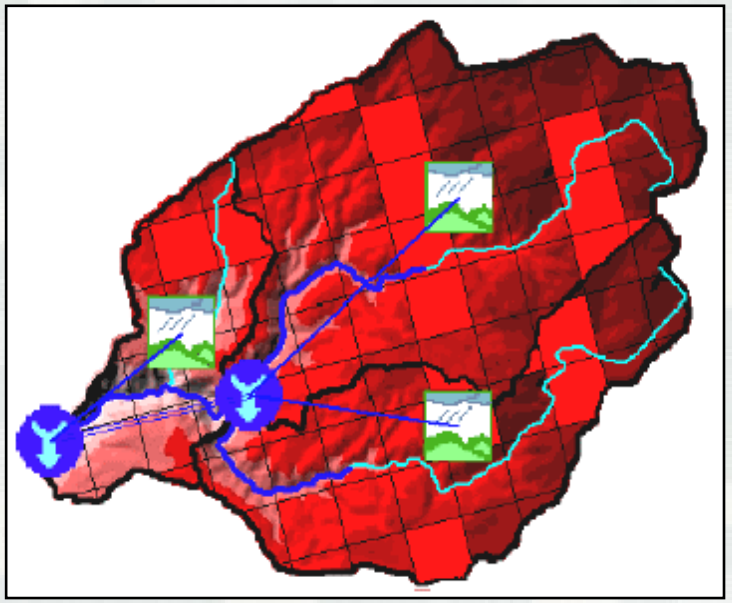


NexGen

- The teams were charged with developing requirements and concepts for their areas, the conclusions are as follows:
  - the software will be integrated and designed for use in a multi-tasking, multi-user environment
  - object-oriented software design and development; languages FORTRAN, C++, VisualBasic; database operations will be through HEC-DSS
  - adherence to published hardware and software standards where available is critical to the success of NexGen
- NexGen's first product was finished in 1995, with the release of HEC-RAS (River Analysis System).

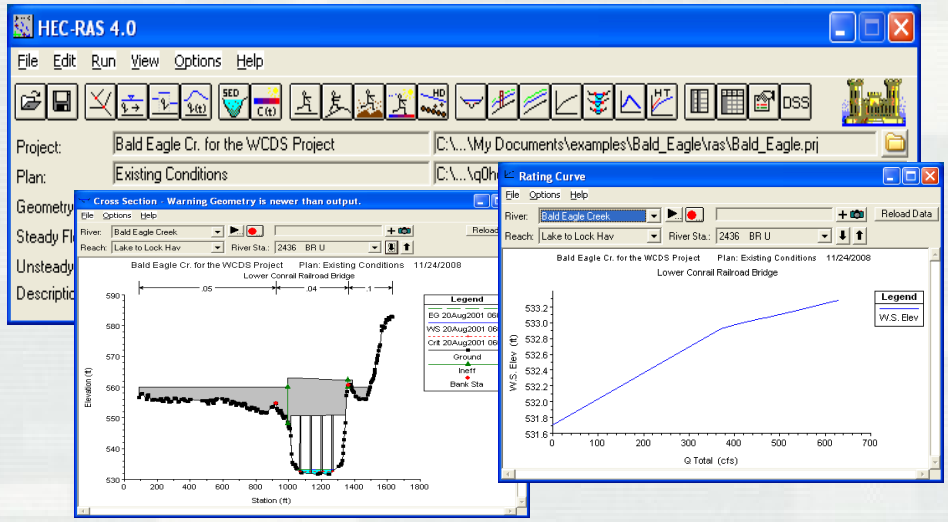
NexGen

- Over the next fifteen years, the software guidelines established have allowed HEC to create software that is consistent in output, graphical user interfaces and the look-n-feel. These guidelines also allow HEC to meet the demands of the ever changing engineering world, new software requirements established by the Corps of Engineers in a manner that is efficient and cost effective.



Fourth Decade
(1994 – 2004)

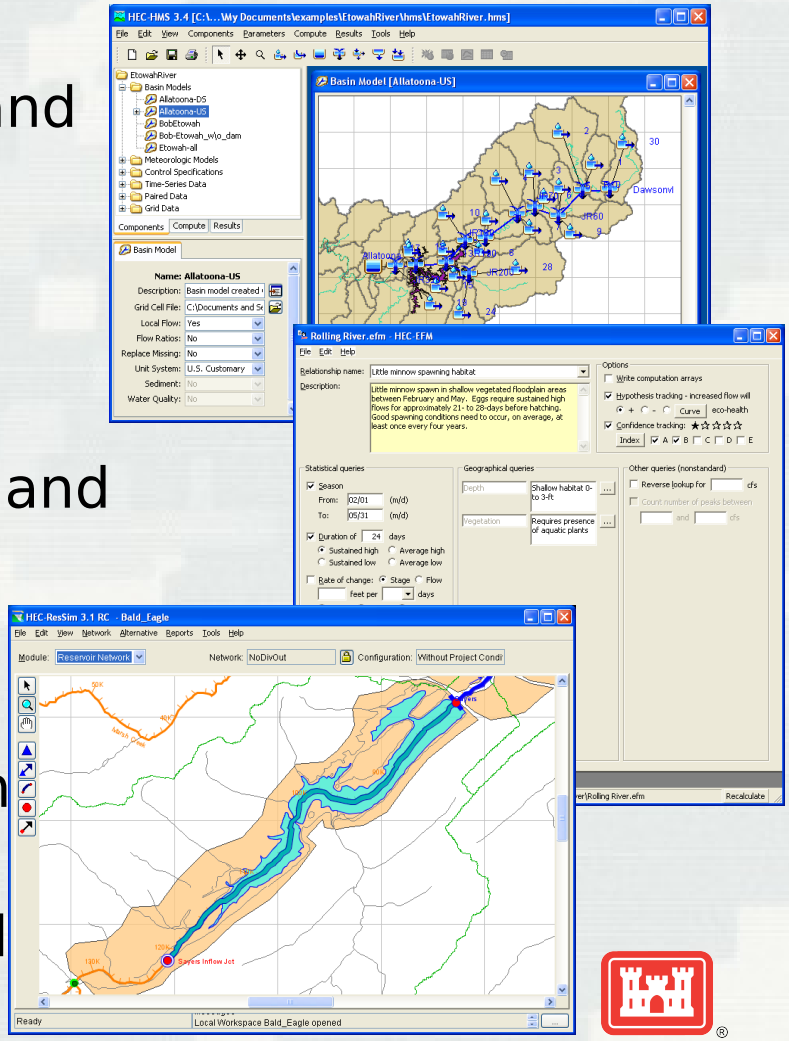
- During the decade HEC continued to develop software to replace the existing software packages.
- The graphical user interfaces and object oriented design have made it much easier to enter and edit data, perform computations and visualize output.



- Graphical displays of cross sections, precipitation, hydrographs, rating curves, profile plot and many other output were now available in graphical format.

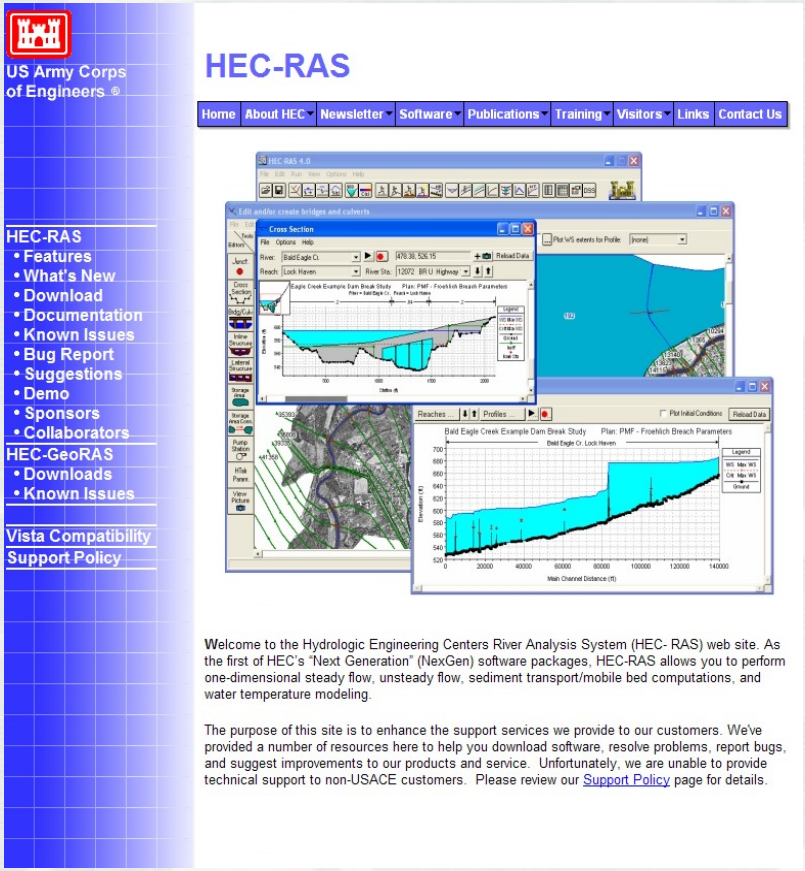
HEC Software Activities

- Hydrologic Statistics with SSP
- Watershed hydrology with HMS and GeoHMS.
- River hydraulics with RAS and GeoRAS.
- Reservoir Analysis with ResSim.
- Flood damage analysis with FDA and FIA.
- Software Integration with CWMS, DSSVue.
- Initial development of Ecosystem Functions with EFM.
- Initial development of Watershed Analysis with WAT and FRM.


HEC-HMS 3.4 [C:\...\My Documents\examples\EtowahRiver\hms\EtowahRiver.hms]
Basin Model [Allatoona-US]
Rolling River.efm - HEC-EFM
HEC-ResSim 3.1 RC - Bald_Eagle

Fourth Decade

- Support for these new software packages included more detailed documentation, training courses, presentations at conferences, and distribution to all from the HEC web page. At the beginning of the decade distribution was done by mailing CDs, but that effort was stopped once the HEC web page came online.


US Army Corps of Engineers ®
HEC-RAS
• Features
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• Download
• Documentation
• Known Issues
• Bug Report
• Suggestions
• Demo
• Sponsors
• Collaborators
HEC-GeoRAS
• Downloads
• Known Issues
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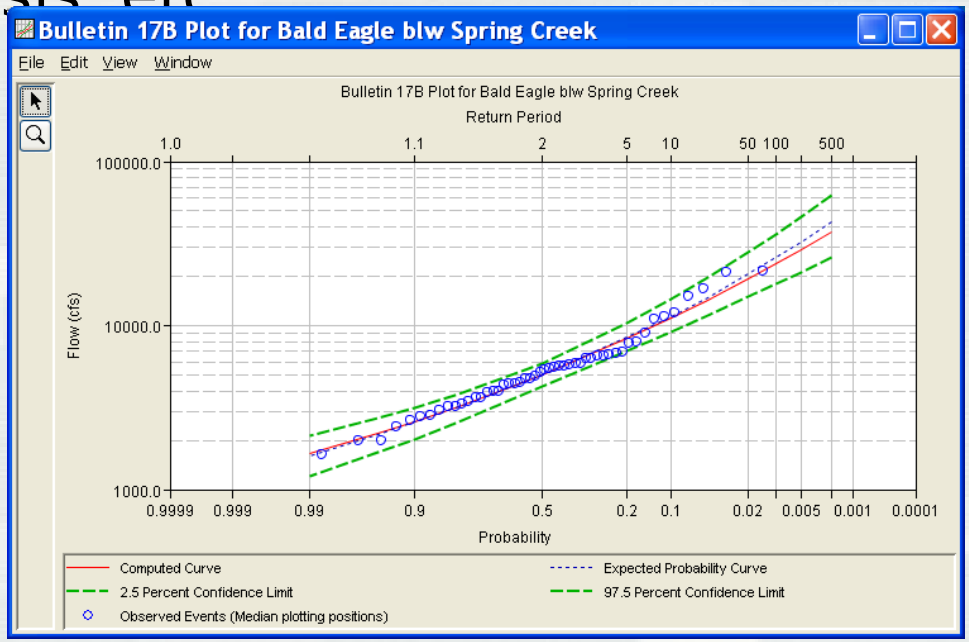
Welcome to the Hydrologic Engineering Centers River Analysis System (HEC- RAS) web site. As the first of HEC's "Next Generation" (NexGen) software packages, HEC-RAS allows you to perform one-dimensional steady flow, unsteady flow, sediment transport/mobile bed computations, and water temperature modeling.
The purpose of this site is to enhance the support services we provide to our customers. We've provided a number of resources here to help you download software, resolve problems, report bugs, and suggest improvements to our products and service. Unfortunately, we are unable to provide technical support to non-USACE customers. Please review our Support Policy page for details.

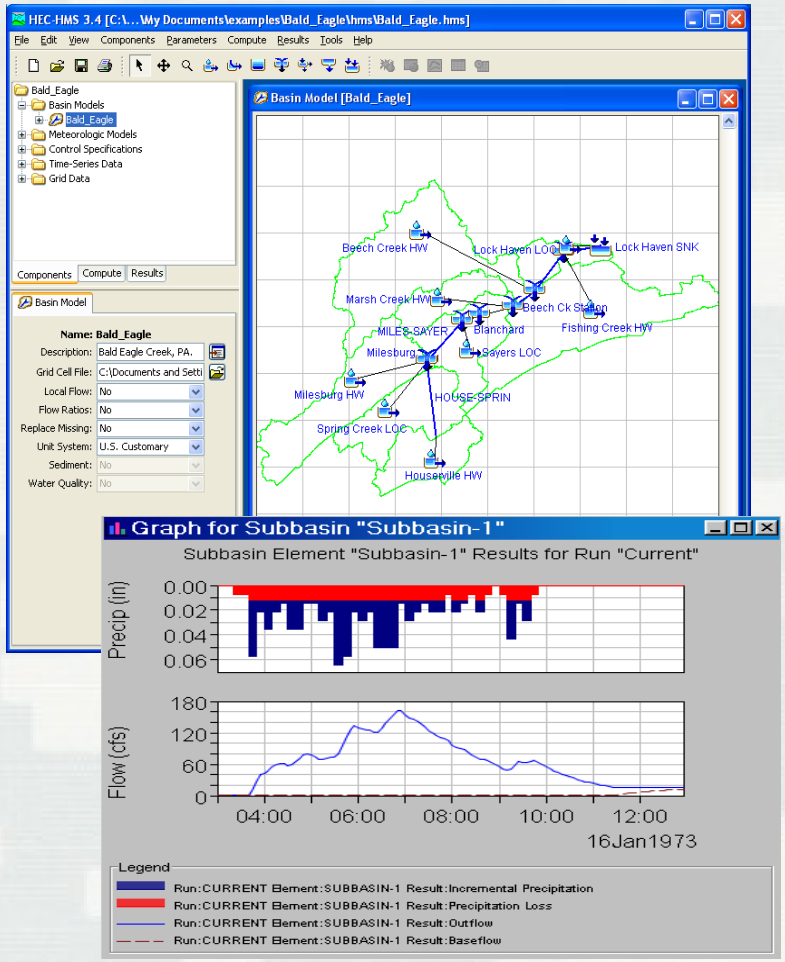
HEC-SSP, Statistical Software Package

Statistical analysis software that supports hydrologic studies. This software performs frequency analysis, regional regression, coincident frequency analysis, duration analysis, etc.

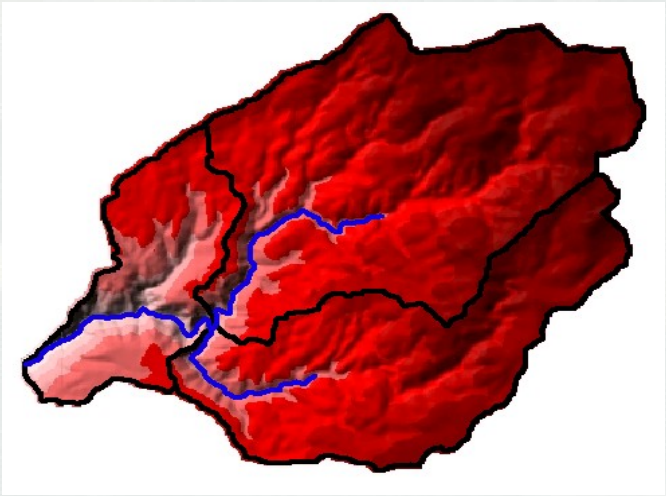

Bulletin 17B Plot for Bald Eagle blw Spring Creek
File Edit View Window
Bulletin 17B Plot for Bald Eagle blw Spring Creek
Return Period
1.0 1.1 2 5 10 50 100 500
100000.0
10000.0
1000.0
Flow (cfs)
0.9999 0.999 0.99 0.9 0.5 0.2 0.1 0.02 0.005 0.001 0.0001
Probability
Computed Curve
Expected Probability Curve
2.5 Percent Confidence Limit
97.5 Percent Confidence Limit
Observed Events (Median plotting positions)

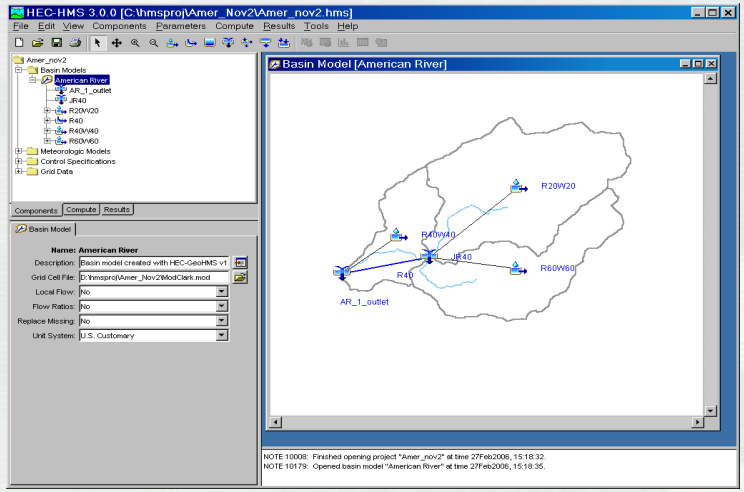
HEC-HMS, Hydrologic Modeling System

- Computes streamflow throughout a river basin given precipitation and watershed characteristics.
- First official released was March 1998; included many of the simulation features from HEC-1 and many additional features including the ability to use gridded precipitation (ModClark), which was a first for hydrologic simulation software.



GeoHMS Preprocessor to HMS





Inputs

DEM

Gage Locations

HUC

RFI

Others

GeoHMS

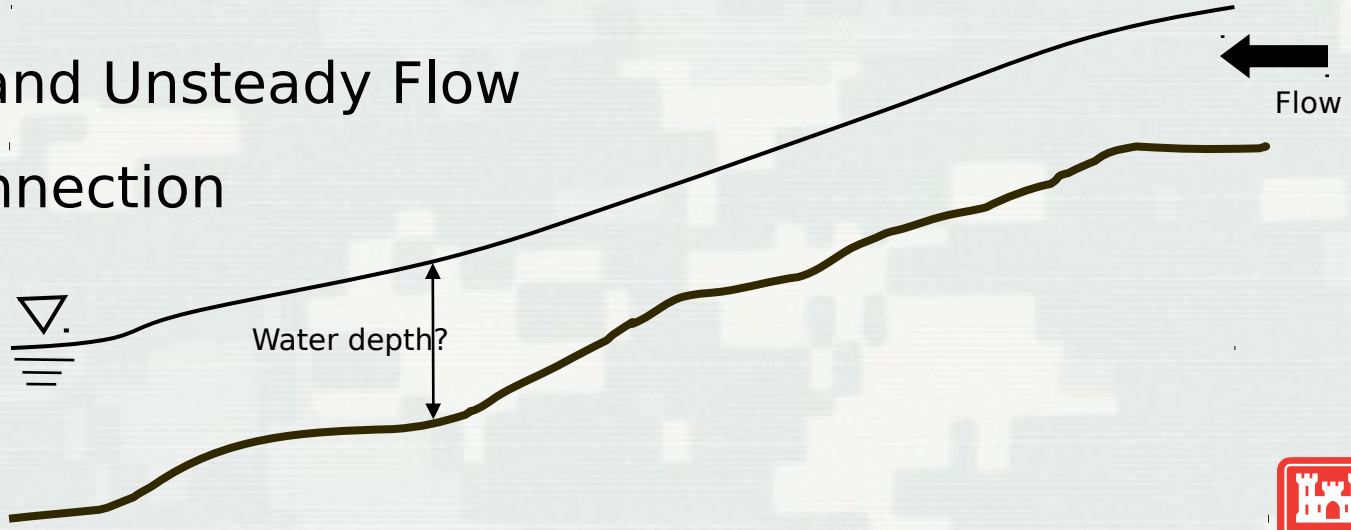
Products

1. Lumped Basin Model
2. Cell Parameter File
3. Distributed Basin Model
4. Background Map File
5. Physical Characteristics of Streams & Watershed Tables

HMS

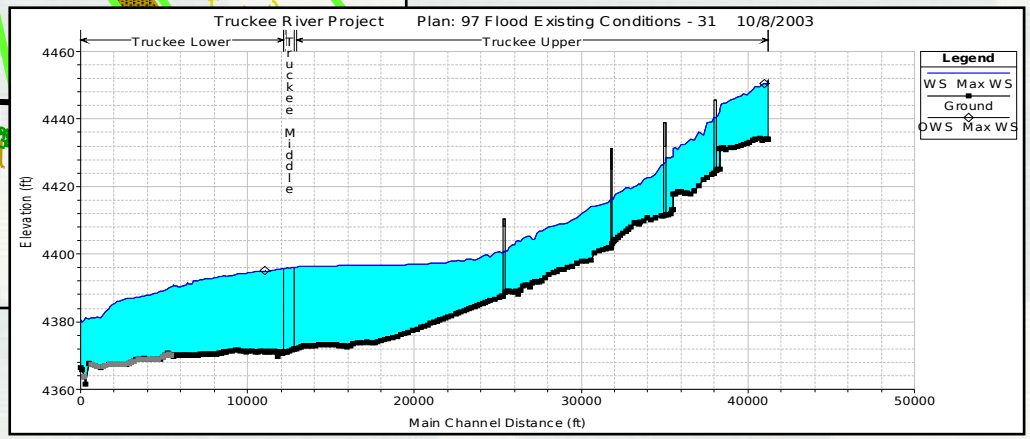
HEC-RAS, River Analysis Systems

- First official release July 1995
- One-Dimensional hydraulics program
- Computes river velocities, stages, profiles, and inundated areas (with GeoRAS) given streamflow and geometry.
- Many advancements over HEC-2
- Steady and Unsteady Flow
- ADH Connection



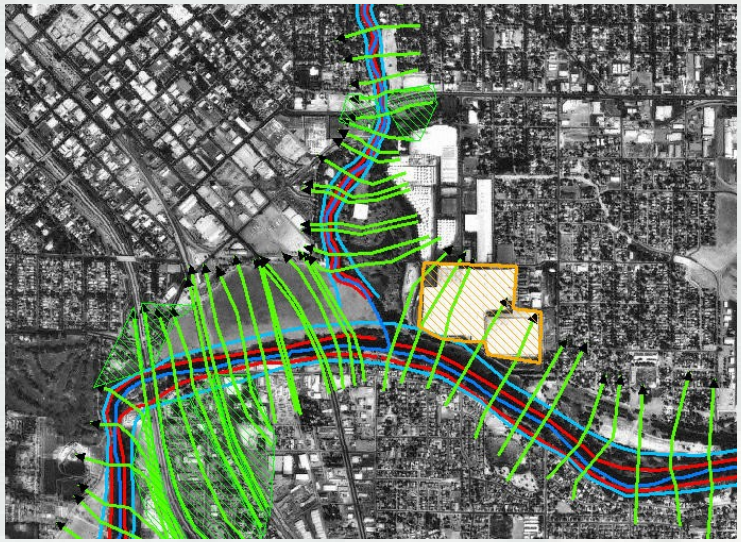
HEC-RAS

Nationally accepted by state and local agencies, academia and Federal agencies such as USACE, FEMA, FHWA, NRCS, NWS and USGS.

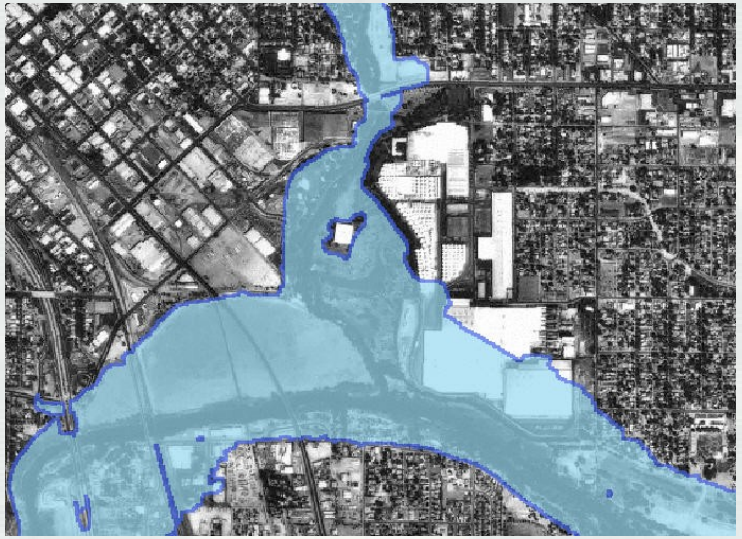


HEC-GeoRAS

- Pre-processor for generating geometric data for HEC-RAS



- Post-processor for mapping and displaying results from hydraulic simulations



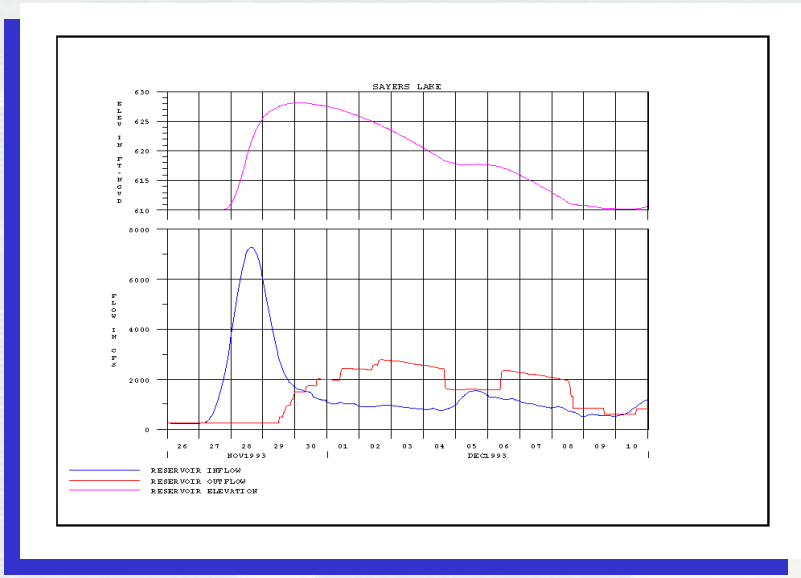
Groundwater/Surface Water Interaction for HEC-RAS

Develop a coupled model that will support improved representation of water exchange where groundwater interaction is a significant component of channel flow, and provide a more complete accounting of water storage in groundwater and channels.

- Evaluation of OpenMI non-proprietary software used for coupling models at the time-step level.
- Algorithm for computing water exchange between HEC-RAS and MODFLOW.

HEC-ResSim, Reservoir System Analysis

- Simulates reservoir operations for flood management, low flow augmentation and water supply for planning studies, detailed reservoir regulation plan investigations, and real-time decision support



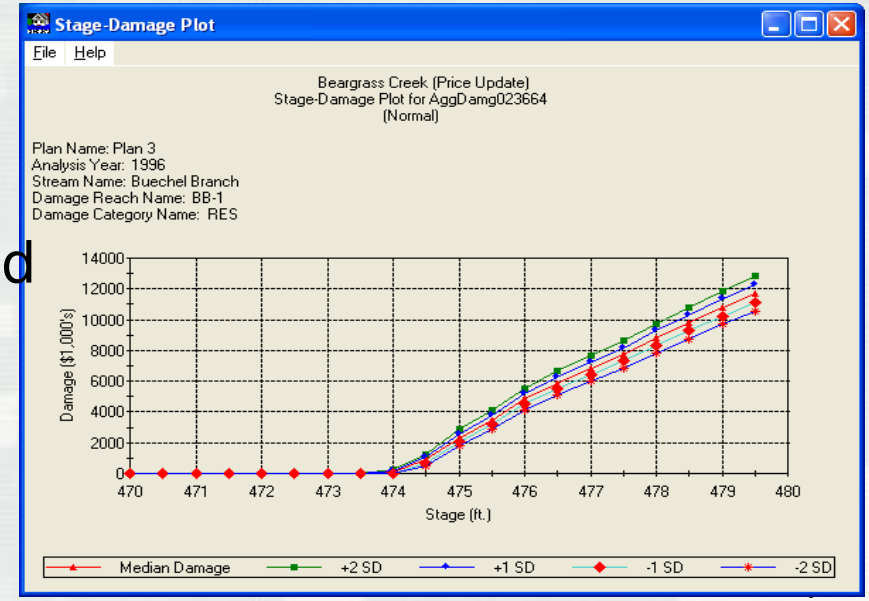
Flood Risk Management Tools

HEC-FDA/HEC-FIA

Software to perform flood risk management analyses; project benefit analysis including loss-of-life consequences; evaluate flood risk management measures using risk and uncertainty and including systems approach and GIS capability

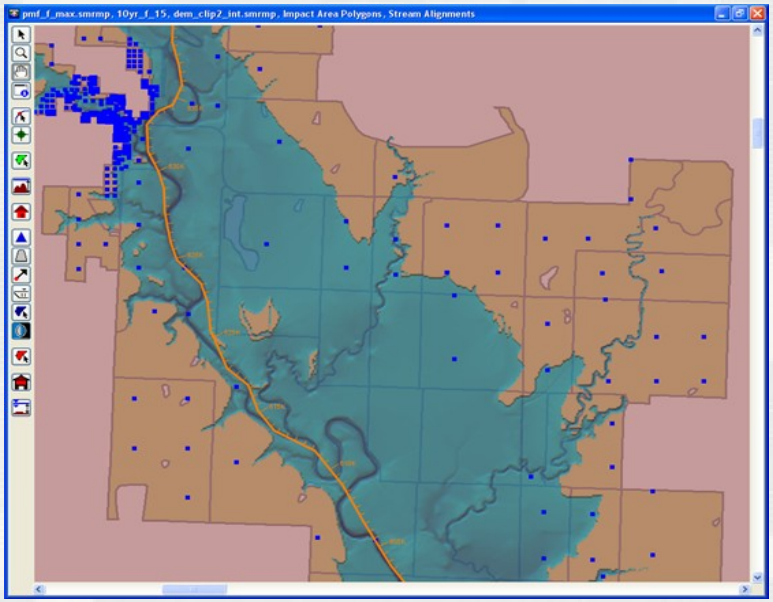
HEC-FDA, Flood Damage Reduction Analysis

- First official release July 1996: Certified in 2008
- Plan Evaluation and Plan Formulation Tool
- Helps answer the question "Which proposed flood damage reduction plan is the best from an economic standpoint?"
  - evaluate the existing condition
  - analyze alternative damage reduction plans
- Compare plans using Expected Annual Damage and damage reduction benefits
- Since 1996, use risk analysis procedures



HEC-FDA

- Version 1.4 will be released soon. Version 2.0 will have a new GUI which will include GIS components; features for evaluating and comparing non-structural measures; compute damages on a structure-by-structure basis using depth grids.



- The GIS capabilities will allow users to readily manipulate, analyze and display spatially referenced data layers when completing a flood damage analysis study. Also, the ability to create structures inventories from parcel maps, census block data or land use shapefiles.

Event Damages with HEC FIA – Flow Impact Analysis

Computes damages to structures and other contents of the floodplain (including agricultural and environmental) given river stages and damage relationships. Also computes Loss-of-life.

CWMS, Corps Water Management System

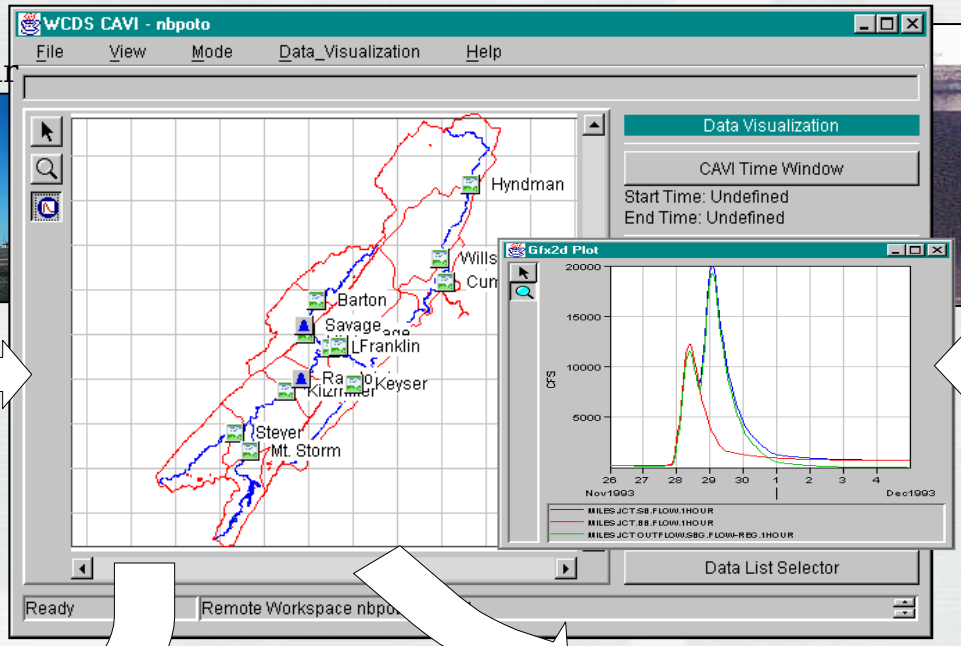
- CWMS is the data acquisition, management, modeling and decision support system that supports the Corps in its real-time water management mission of regulating more than 700 dam and reservoir projects, control structures and thousands of miles of levees.
- CWMS is a nationwide standard, corporately supported integrated system of hardware, real-time software and other resources that acquires, analyzes, and stores data; develops decision support information; and allows user access to any data and information on the system.
- From 40 existing unique systems to one CWMS.

CWMS

Real-Time Fully Integrated Hydrologic Models

Weather Radar

Streamgages



Operational Decisions

Inundation Forecasts

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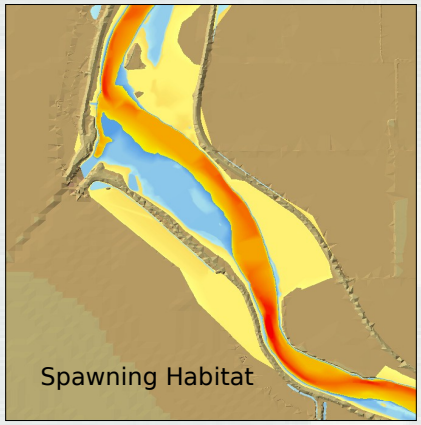
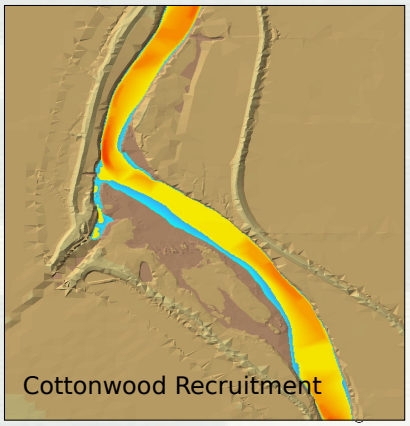
HEC-EFM, Ecosystems Functions Model

- Planning tool for flow regime change.
- Reservoir/regulation change, diversions, remove/set back levee, reconfigure channel.
  - ► Impact on terrestrial and aquatic habitat.
  - ► Change direction/magnitude - biologic impact.
  - ► Team use: biologists, geomorphologists, hydraulic engineers, environmental managers.
- Premise: hydrologic/hydraulic data can help predict biologic response.

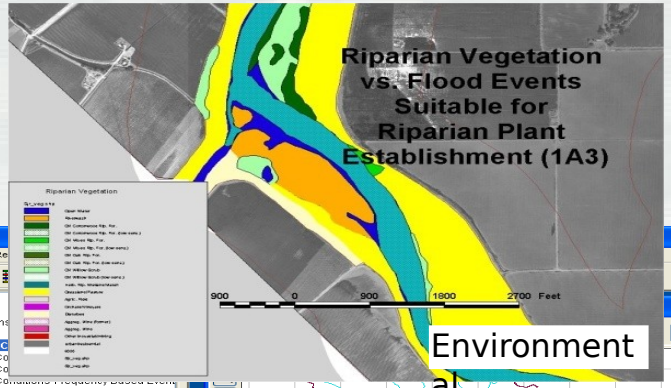




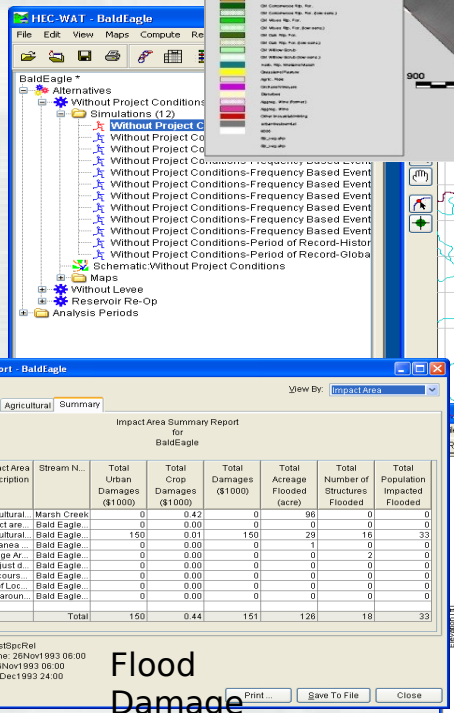
Future Directions: HEC-WAT, Watershed Analysis Tool

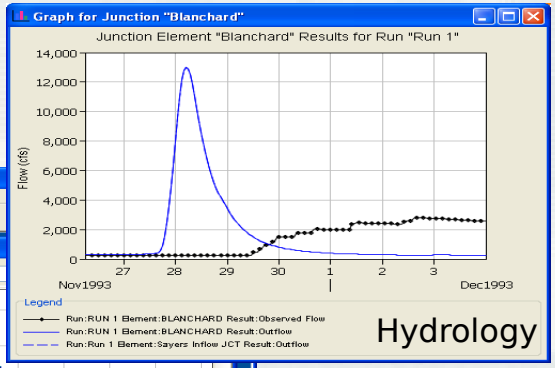
- Interface that streamlines and integrates the analytical process of Water Resource Studies using the tools commonly applied by multi-disciplinary teams. Includes: hydrologic, hydraulic, economic, environmental, and social impact assessments.
- Help offices perform all types of studies including IWRM Studies and small CAP studies in an integrated fashion.
- Provides a central organized repository of data/models/results.

HEC-WAT


Riparian Vegetation vs. Flood Events Suitable for Riparian Plant Establishment (1A3)
Riparian Vegetation
900 0 900 1800 2700 Feet

Environmental

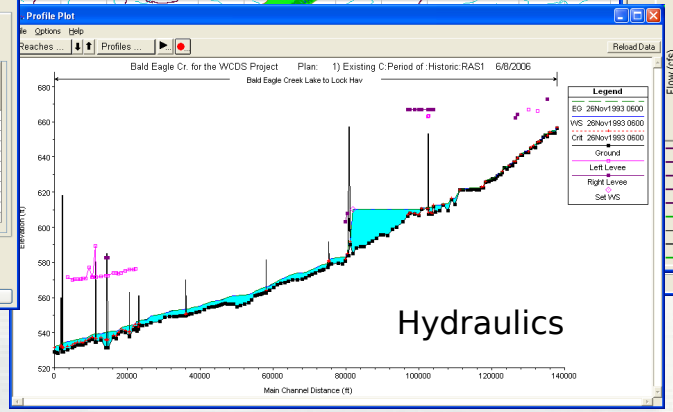




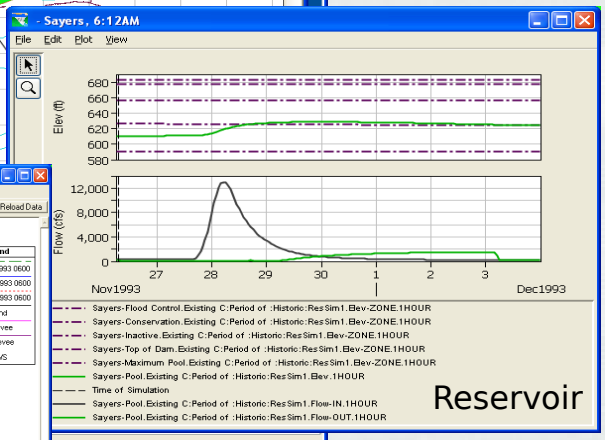
Hydrology

Alternative Report - BaldEagle
View By: Impact Area
Urban Structures Agricultural Summary
Impact Area Summary Report for BaldEagle
Alternative Name: HistSpcRel
Lookback Date & Time: 26Nov1993 06:00
Start Date & Time: 26Nov1993 06:00
End Date & Time: 03Dec1993 24:00
Print... Save To File Close

Flood Damage



Hydraulics



Reservoir

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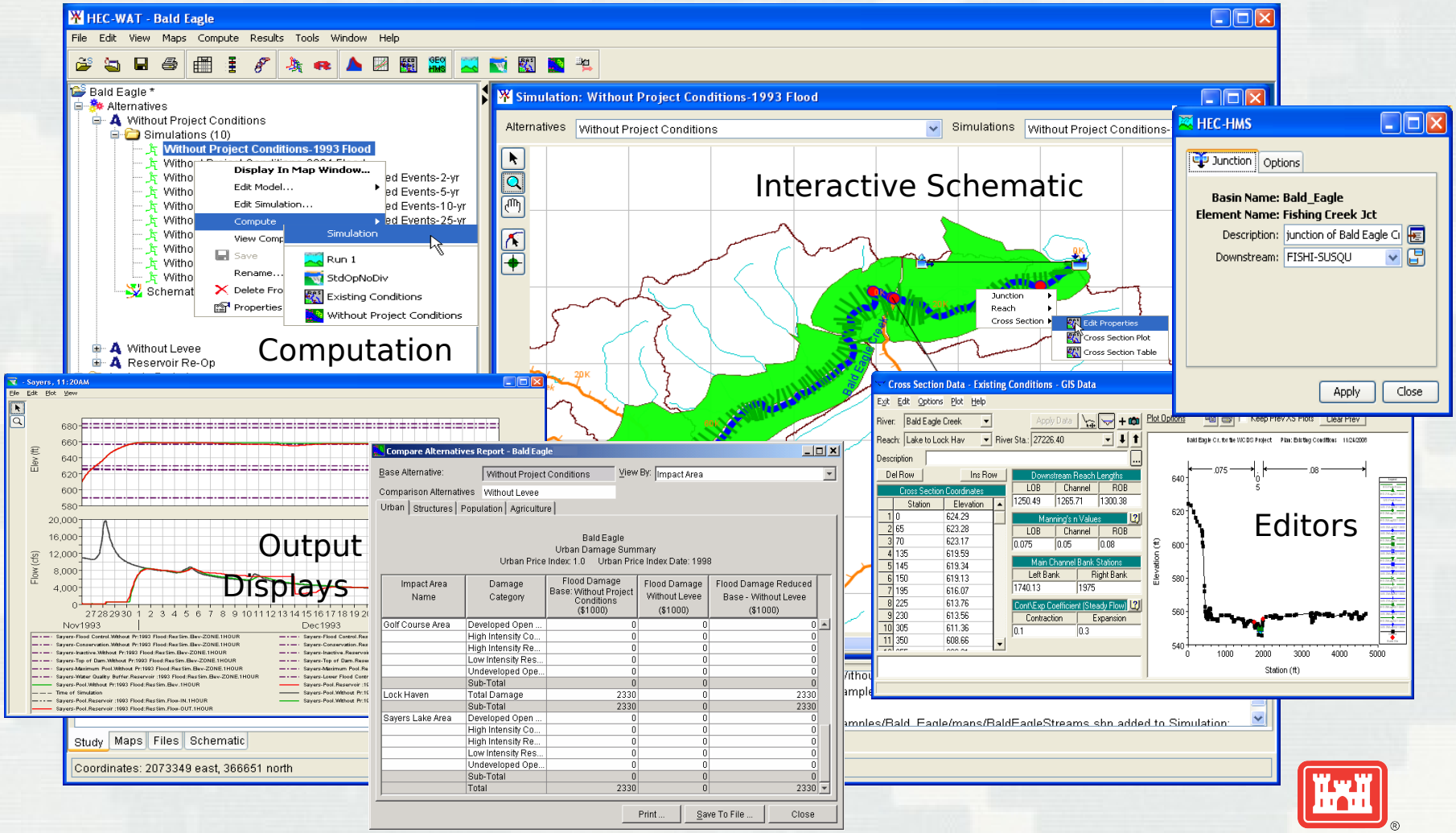
HEC-WAT Model Integration

Integrate model and tools used during the analytical process:

- Hydrology - HEC-HMS & GeoHMS - *Done*
- Reservoir Operations - HEC-ResSim - *Done*
- Hydraulics - HEC-RAS & GeoRAS - *Done*
- Economics - HEC-FIA - *Done*
- Statistical – HEC-SSP – *Done*
- Data – HEC-DSSVue – *Done*
- Environmental - HEC-EFM – *Done*
- Future Additions – HEC-FDA, RiverWare …

HEC-WAT



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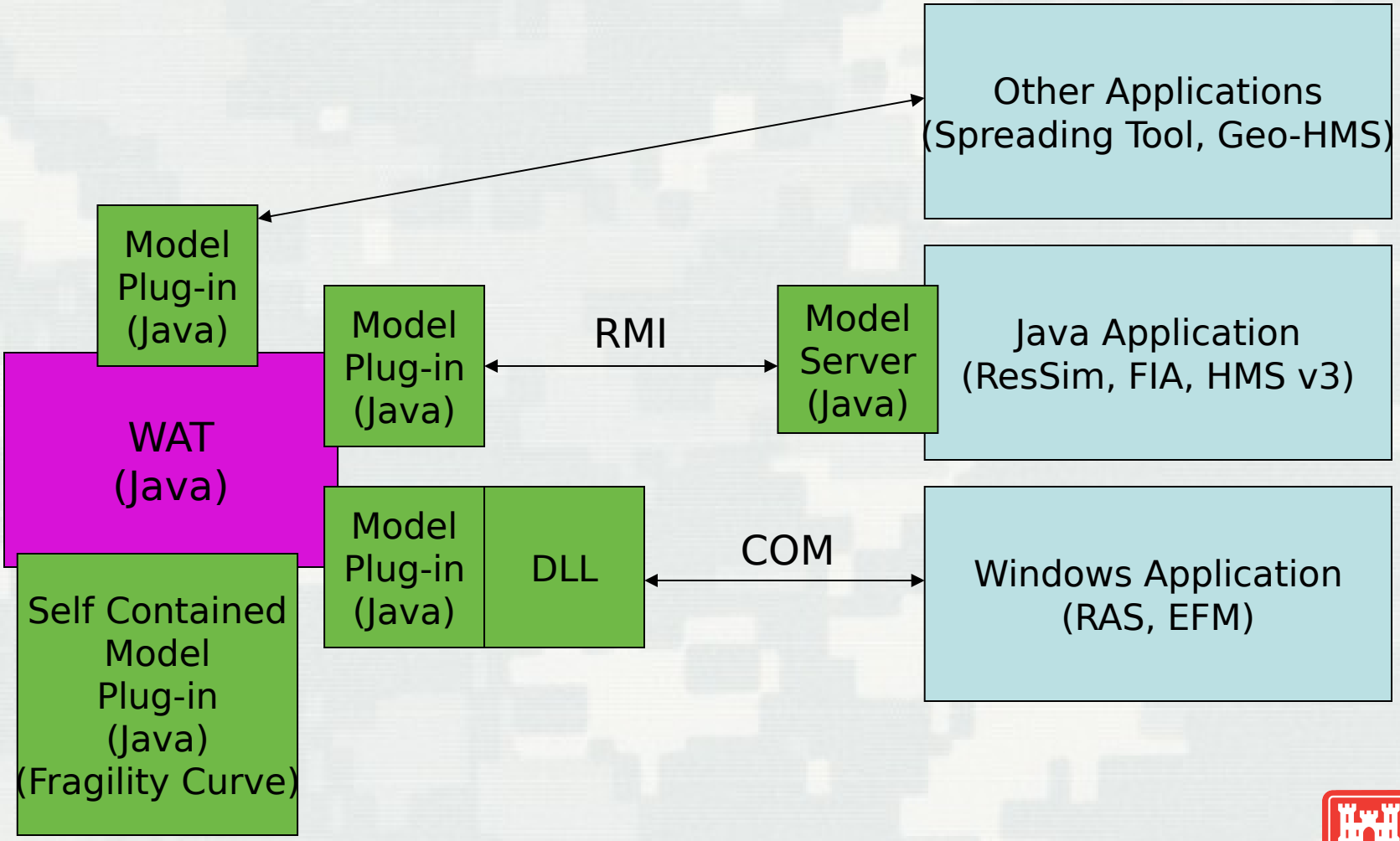
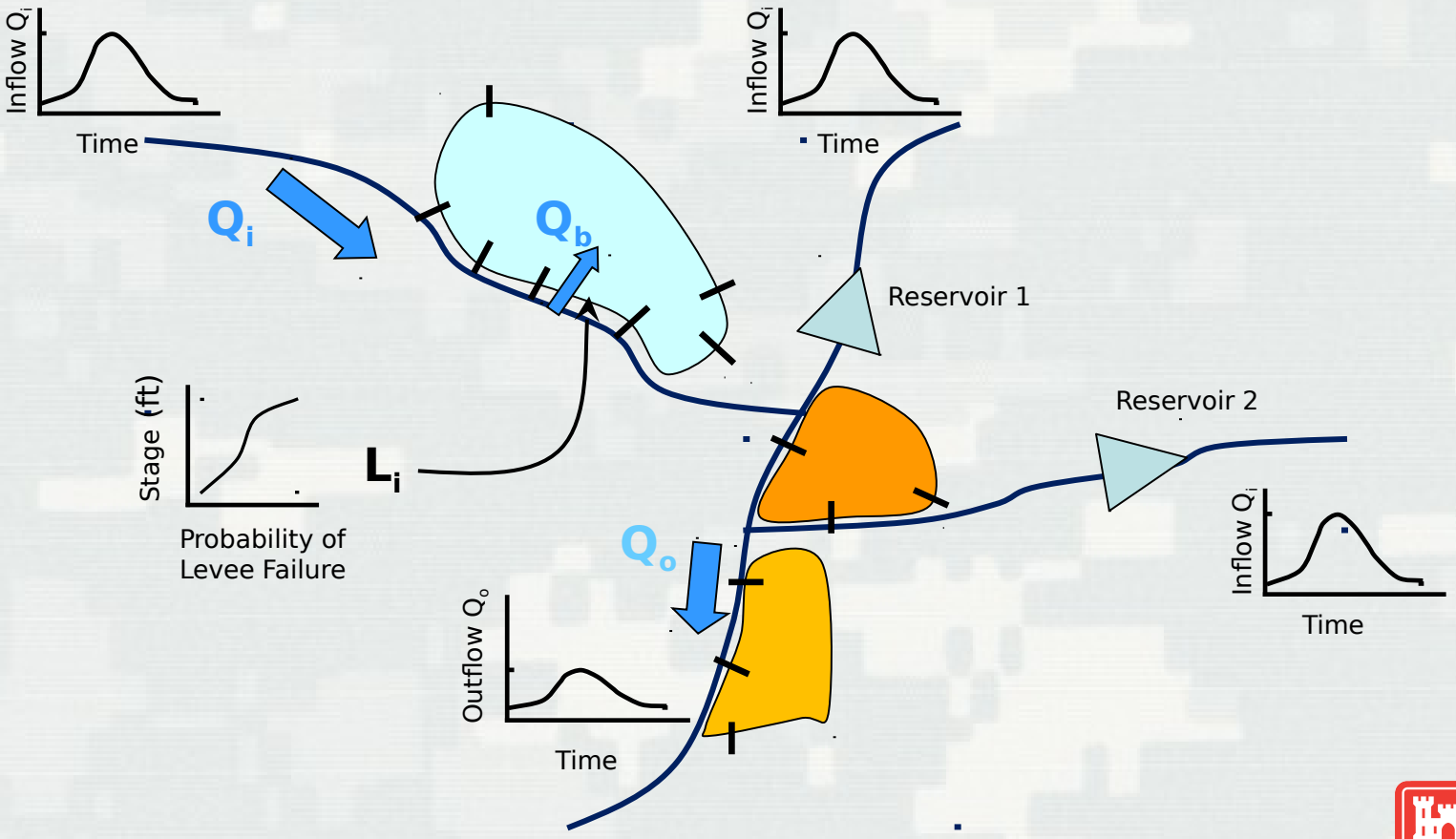
Plug-In Architecture



FRM Module - HEC-WAT

- Systems approach for assessing risks and uncertainties in simple systems as well as complex, interdependent systems.
- Tool for reconnaissance and feasibility studies.
- Incorporate social and environmental consequences.
- Tool for levee assessment and certification.
- Effective at risk communication.
- Incorporate new computational methodologies.

FRM Load Distribution



FRM – Computational Challenges

- How to generate flood events?
  - Discharge Frequency Based
  - Synthetic Approach
  - Both have pros and cons
- How to automate thousands of hydrodynamic simulations? (e.g. unsteady HEC-RAS runs)
- How to model multiple failure modes?
- How to evaluate consequences?
- How to reduce computational burden?

Vision for WAT/FRM

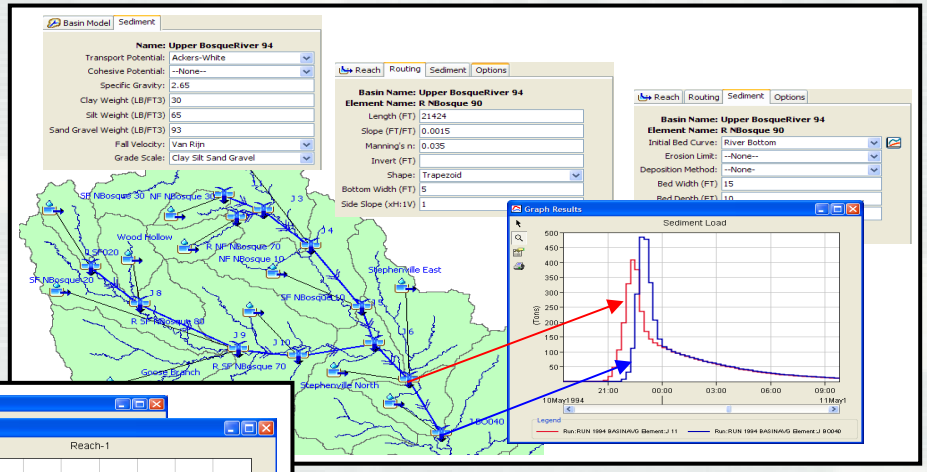
- IWRM is the way of the future.
- Existing, tested, corporate software can be used for IWRM.
- The WAT/FRM is a program that integrates models and provides coordination and analysis for water resource studies.
- Integrates major HEC programs, such as SSP, HMS, GeoHMS, RAS, GeoRAS, ResSim, FIA, DSSVue, FDA, EFM etc.
- Visualization tools to create and edit models and compare alternatives creates a transparent, open, collaborative and trusting modeling environment.

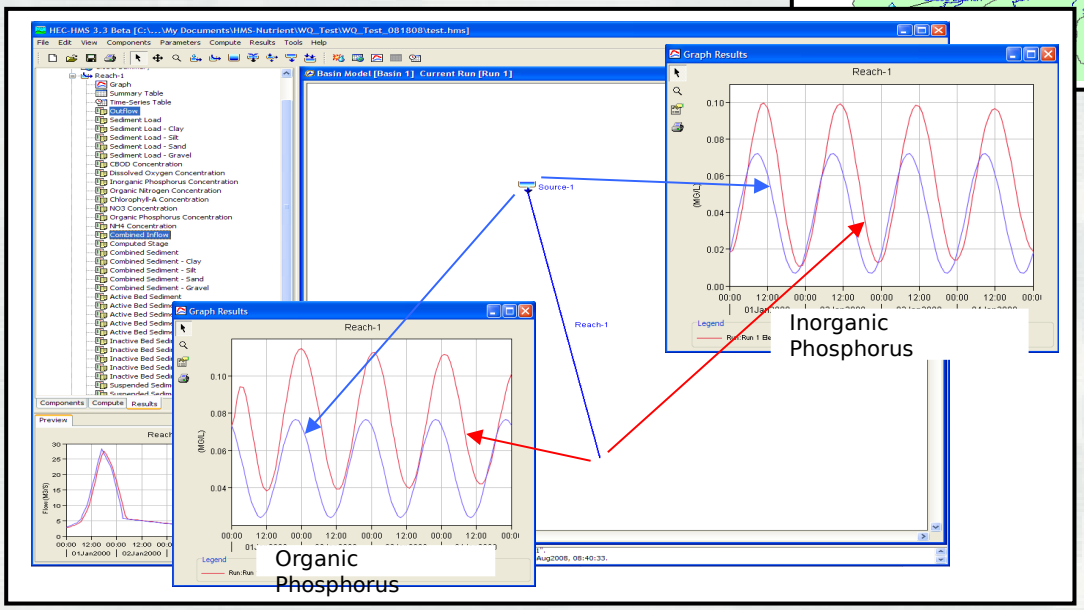
Future Directions: HEC Ecosystem/Environmental Activities

- Hydrologic Modeling Systems (HEC-HMS)
- River Analysis System (HEC-RAS)
- Reservoir Simulation Model (HEC-ResSim)
- Regime Prescription Tool (HEC-RPT)
- Ecosystem Functions Model (EFM)

HEC-HMS

- Current work includes an erosion and sediment transport module, and water quality development through ERDC's EL using NSM.





- HMS represents over four decades of HEC experience with hydrologic simulation and will continue to evolve.

Sediment, Temperature & WQ in HEC-RAS

- Coordinated with EL using NSM.
- Added water temperature modeling and sediment transport to HEC-RAS.
- Also, added water quality constituents to the HEC-RAS analysis process by incorporating the water quality computations of QUAL-RIV1 into HEC-RAS:
  - ► Temperature
  - ► CBOD
  - ► ORG-N, NH3-N, NO3-N
  - ► ORG-P, ORTHO-P
  - ► Dissolved MN
  - ► Dissolved FE
  - ► DO
  - ► Coliform
  - ► Algae

Reservoir Water Quality Enhancements

HEC-ResSim & CE-QUAL-W2

- ResSim a multi-objective reservoir simulation tool used for real-time operations and planning studies.
- CE-QUAL-W2 a reservoir tool used for water quality and temperature studies.
- Demand for water quality and temperature modeling for real-time and planning analyses.
- Coordination with ERDC's EL.
- Linking models through OpenMI (Open Model Interface) rather than fund a major development effort.
- Will provide in and downstream of the reserv
  - Temperatures
  - Dissolved Oxygen
  - Other conservative constituents
  - Variable gate settings

Regime Prescription Tool
Reservoir Operations
(software to improve interaction while defining ecosystem flow regimes)

- Need identified as a direct result of the Corps and TNC's partnership on the Sustainable Rivers Project – Savannah River Comprehensive Study.
- First piece of software jointly developed and financed through the SRP.
- Allows parties to:
  - Define wet, dry, or average flow years.
  - script flow regimes to include flood, pulse, and base flows.
  - Use with the EFM and ResSim to help make planning and operational decisions.
  - Eventually could be used within ResSim to make real-time operational decisions.

QUESTIONS?

US Army Corps of Engineers
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